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The impact of genetics on retail meat value in Australian lamb.

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Abstract

Lean (muscle), fat, and bone composition of 1554 lamb carcasses from Maternal, Merino and Terminal sired lambs was measured using computed tomography scanning. Lamb sires were diverse in their range of Australian Sheep Breeding Values for post weaning c-site eye muscle depth (PEMD) and fat depth (PFAT), and post weaning weight (PWWT). Lean value, representing predicted lean weight multiplied by retail value, was determined for lambs at the same carcass weight or the same age. At the same carcass weight, lean value was increased the most by reducing sire PFAT, followed by increasing PEMD and PWWT. However for lambs of the same age, increasing sire PWWT increased lean value the most. Terminal sired lambs, on average,

had greater lean value irrespective of whether comparisons were made at the same age or weight. Lean value was greater in Merino compared to Maternal sired lambs at equal carcass weight, however the reverse was true when comparisons were made at the same age.

1 Introduction

Hot carcass weight (HCWT) and lean meat yield percentage (LMY%) are important profit drivers across the entire value chain, but especially for processors. The value of HCWT is relatively easy to understand as it represents increased volume of product per fixed cost of slaughter and fabrication of cuts. Alternatively, the financial implications of LMY% are more complex. For processors, leaner lambs require less fat trimming, resulting in less wastage and decreased processing costs (Hopkins, 1989). Furthermore, the location of lean in the carcass also influences carcass value, as the price of different cuts vary at retail. Therefore a carcass with proportionately more lean within the higher value loin cuts, will be worth more (Pethick, Ball, Banks, & Hocquette, 2011). To reflect these profit drivers, Australian processors purchase lambs on the basis of HCWT and GR tissue depth (tissue depth at the 12th rib 110mm from the midline) to crudely reflect LMY% (Pethick et al., 2011).

To indirectly select for LMY% and HCWT, Australian lamb producers make use of Australian Sheep Breeding Values (ASBVs) for sire post-weaning weight (PWWT), c-site fat depth (PFAT) and eye muscle depth (PEMD). All three breeding values have been shown to increase HCWT (Gardner et al., 2015), with PWWT having the biggest impact producing heavier lambs at the same age, or enabling earlier slaughter at a targeted weight. Producers also utilise the carcass breeding values to indirectly select for LMY%, with a breeding value for direct selection for this trait not currently utilised in Australian lamb breeding programs. A recent study by Anderson, Williams, Pannier, Pethick and Gardner (2015a) used computed tomography (CT) to assess lamb carcass composition and revealed that when compared at the same carcass weight, the progeny of sires with increased PEMD and decreased PFAT had a greater proportion of lean in the carcass. Additionally, it was observed that the increase in lean was preferentially distributed to the saddle (mid) section of the carcass (Anderson, Williams, et al., 2015a), a finding supported by earlier studies (Gardner et al., 2010; Hall, Gilmour, Fogarty, & Holst, 2002; Hegarty et al., 2006). Sire PWWT ASBV was shown to increase the proportion of lean in the saddle region, although the effect on carcass LMY% was smaller and less consistent than that of sire PFAT and PEMD (Anderson, Williams, et al., 2015a). The combined effect of these breeding values on LMY% and distribution of lean and therefore carcass value has not been determined. When comparing lambs at the same carcass weight we would expect sire PFAT to have the greatest increase on carcass value, followed by sire PEMD and PWWT. Alternatively, when comparing lambs at the same age HCWT will be the main profit driver, hence PWWT is expected to have the biggest impact on carcass value.

Differences between sire types have also been shown to impact carcass composition (Anderson, Pannier, Pethick, & Gardner, 2015; Anderson, Williams, et al., 2015a; Anderson, Williams, Pannier, Pethick, & Gardner, 2015b; Ponnampalam, Hopkins, Butler, Dunshea, & Warner, 2007). Terminal sired lambs have been shown to grow the fastest (Gardner et al., 2015), and when compared at the same carcass weight, they also have a greater proportion of carcass lean than Maternal and Merino sired lambs (Anderson, Williams, et al., 2015a; Ponnampalam et al., 2008). Therefore their carcass value should be higher irrespective of whether compared at the same weight or age.

This experiment analyses data from a large number of lamb carcasses (1554) from the Information Nucleus Flock (INF) experiment which is run by the Australian Cooperative Research Centre for Sheep Industry Innovation (Sheep CRC). Previous analyses of the lamb carcasses from this experiment have examined the impacts of genetic and non-genetic factors on carcass composition and distribution of fat, lean (muscle) and bone and are reported in Anderson, Williams et al. 20015a,b. Alternatively, this analysis expresses these changes in absolute mass and the equivalent dollar value, thus focussing on the financial implications that genetic selection for sires high in PWWT and PEMD and low in PFAT has on the value of lean in the carcass. We hypothesise that when compared at the same carcass weight, selection of lambs for increased sire PWWT and PEMD and decreased PFAT will result in a higher carcass value through an increase in LMY%, with PFAT having the greatest impact. However, when compared at the same age we hypothesise that PWWT will have the greatest impact on carcass value. Finally, we hypothesise that the carcass value of Terminal sired lambs will be greater compared to Merino and Maternal sired lambs when compared at either the same weight or the same age.

2 Materials and Methods

2.1 Experimental design and slaughter details.

The design of the Sheep CRC INF is described by Fogarty, Banks, van der Werf, Ball, and Gibson (2007). In brief, approximately 10,000 lambs were produced by artificial insemination of Merino or Border Leicester-Merino (BLM) dams over a 5 year period (year 2007-2011) at eight research stations (Katanning WA, Cowra NSW, Trangie NSW, Kirby NSW, Struan SA, Turretfield SA, Hamilton VIC, and Rutherglen VIC). The sire types used in the INF included: Terminal sires (Hampshire Down, Ile De France, Poll Dorset, Southdown, Suffolk, Texel, White Suffolk), Maternal sires (Bond, Booroola Leicester, Border Leicester, Coopworth, Corriedale, Dohne Merino, East

Friesian, Prime South African Meat Merino (SAAM), White Dorper), and Merino sires (Merino, Poll Merino). The combinations of sire and dam crosses included: Merino, Maternal x Merino, Terminal x Merino and Terminal x BLM. Lambs were weaned at approximately 100 days of age, grazed under extensive conditions and supplemented with feed at times when there was limited pasture, with availability of pasture and feed varying between sites (Ponnampalam et al., 2014). All male lambs were castrated.

The lambs were divided into groups based on live weights, with each group killed separately (kill groups) targeting a hot carcass weight at slaughter of between 21 to 24kg, irrespective of condition score. Lambs within kill groups were on average within 5 days of age of each other and within a year there was an attempt to represent all sire types in each kill group. Within each site, the aim of selection of lambs for CT was to include at least two progeny from each sire used at the site, selected across a live weight strata. At all INF sites, lambs were yarded within 48 hours of slaughter, maintained off-feed for at least 6 hours, and then weighed to determine pre-slaughter live weight. Lambs were then transported for 0.5-6 hours via truck to one of 5 commercial abattoirs, held in lairage at the abattoir for between 1 and 12 hours, and then slaughtered. All carcasses were subjected to medium voltage electrical stimulation (Pearce et al., 2010) and trimmed according to AUSMEAT standards (Anonymous, 2005) and HCWT was then measured within 40 minutes of slaughter. All lambs were measured and sampled for a wide range of carcass and meat quality traits (Pearce, 2009).

2.2 Computed tomography scanning

Lambs used in the CT study of composition were slaughtered and carcasses transported to either Murdoch University (Picker PQ 5000 spiral CT scanner) or the University of New England (Picker, Bavaria, Germany) for scanning within 72 hours of slaughter to determine the proportions of fat, lean and bone. Lamb carcasses were divided into three sections (fore, saddle (middle) and hind): the fore section separated from the saddle by a cut between the fourth and fifth ribs; the hind section was separated from the saddle by a cut through the mid-length of the sixth lumbar vertebrae. A detailed description of the CT scanning process and calculation of carcass composition is presented in Anderson, Williams et al. (2015a).

2.3 Data used

This experiment utilised the HCWT results obtained from an experiment described by Gardner et al. (2015) for the progeny born from 2007 to 2010. This included 7516 lambs, representing the progeny of 76 Maternal, 127 Merino and 135 Terminal sires for which breeding value data were available. The breeding values for PEMD and PFAT are based upon live ultrasound measurement at the c-site (located at the 12th rib 45mm from the midline), and PWWT is based upon live weight, all measured at the post weaning time point (about 240 days of age).

CT scanning data was available on 1554 of the lambs from an INF experiment described by Anderson, Williams et al. (2015a) using 7 site-year combinations where lean measurement was available within the fore, saddle, and hind sections of the carcass (Table 1). In this experiment there were a total of 23 kill groups, with the raw average age of lamb 280 days and the number of lambs within each kill group ranging from 20 to 99 lambs (Table 1). The mean weight (and range) of the lamb carcasses in this experiment was 23.3kg (13.3-40.0 kg), with the weight (and range) of fat being 6.3kg (2.1-15.3), lean 13.3kg (7.4-20.8), and bone 3.8kg (2.4-5.7) respectively. The full description of carcass weights of fat lean and bone across the three sections are reported in Anderson, Williams et al. (2015a). Of the 81 Maternal, 119 Merino and 144 Terminal sires in the CT experiment, 67, 109 and 143 had ASBV values for PWWT, PEMD, PFAT and Carcass Plus Index available with the mean and range of these breeding values shown in Table 2.

In both the HCWT analysis and CT analysis, a percentage of sires selected in a year were used in subsequent years to provide sire linkage between years. The ASBV values were sourced from Sheep Genetics, which is Australia's national genetic evaluation database for sheep (Brown et al., 2007). The sire breeding values and index estimates were generated within 3 separate data-bases for Terminal, Maternal, and Merino sired progeny and were from an analysis completed in April 2013. Some of the youngest sires used in this experiment lacked industry records and therefore did not have ASBVs available. For the CT analysis of lean distribution this meant that there were 1501 lambs with known ASBVs for the analysis.

2.4 Data transformation

All data in the lean analysis were converted to natural logarithms in order to utilise Huxley's allometric equation ($y = ax^b$.) (Huxley & Teissier, 1936). Where x is the independent variable (carcass weight), a is the proportionality coefficient and b the growth coefficient of y (weight of each tissue within a section) relative to x. By transforming all of the values to natural logarithms the equation becomes: $\log_e y = \log_e a + b.\log_e x$; which linearises the data and can then be solved for y by least squares regression.

A significant advantage of using the $\log_e$ form of the equation is that it homogenises the variance over the entire range of sample data. It also allows for the direct comparison of the differences in log y values as percent differences (Cole, 2000) in lean weight of a section at a given carcass weight or back-transformation to give the weight (kg) of the tissue (lean) in each section. The $\log_e$ transformation introduces a systematic bias into the calculations and it is well recognised that a correction factor is required to correct for this bias when back-transforming predictions (Baskerville, 1972; Beauchamp & Olson, 1973; Sprugel, 1983). Hence the correction described by Sprugel (1983) was used when data were back-transformed from $\log_e$ lean weight to kg lean weight.

2.5 Establishing models for predicting section lean weights.

Linear mixed effects models in SAS (SAS version 9.0, SAS Institute, Cary, NC, USA) were used to determine the factors affecting the weights of muscle, bone, and fat for each carcass section. A series of 9 base models were established, where the dependent variables were the $\log_e$ weights (kg) of these tissues within each section, including $\log_e$ (fore section fat, lean, bone); $\log_e$ (saddle section fat, lean, bone) and $\log_e$ (hind section fat, lean, bone). The covariate (x) was $\log_e$ whole carcass weight (kg), fixed effects included: site-year (combined effect of site and year of lamb birth: Katanning (2008, 2011), Kirby (2007, 2008,) Hamilton 2009, Turretfield 2009 and Struan 2010); birth type and rearing type (combined effect of animals born as single, twin or triplet and reared as single, twin or triplet); sire type (Maternal, Merino and Terminal); sex within sire type (wether Merino, wether Maternal, female Terminal, wether Terminal); dam breed within sire type (Merino x Merino, Maternal x Merino, Terminal x Merino, Terminal x BLM) and kill group within site-year, and random terms included sire and dam identification by lamb birth year. The 1554 carcasses with entries for sex, sire type, birth-type rear-type, dam breed, and kill group were included in the base model (Table 3). It was initially established that there were no first order interactions of the b term with and of the core terms (sire type, sex within sire type, dam breed within sire type, birth type-rear type, site year, site year within kill group). The 9 base models were constrained to maintain the same form allowing the relative increases and decreases in carcass components within each section to offset each other so that the predicted weights of the components would be additive to equal the weight of the carcass. To identify this consistent form we initially used a single multivariate model which was derived using all of the 9 $\log_e$ weights (kg) of the tissues within each section as the dependent variables, and the covariate and fixed effects described above as independent variables. All relevant interactions between fixed effects and the covariate ($\log_e$ carcass weight) were tested within this multivariate model and removed in a stepwise manner if non-significant ($P>0.05$).

In a secondary analysis, the above procedure was repeated with the sire ASBVs for PWWT, PEMD and PFAT included in the base model along with their first order interactions with the fixed effects. This included the interaction between ASBVs and sire type, which was particularly relevant given that the breeding values were derived from 3 separate data-bases for Terminal, Maternal, and Merino sired progeny, and thus their magnitudes may not be directly comparable. Non-significant ($P > 0.05$) terms were removed in a stepwise manner. Although these ASBVs were correlated (PWWT vs PEMD = 0.3; PWWT vs PFAT = 0.3; PEMD vs PFAT = 0.1) previous analysis has demonstrated that their effects are still relatively independent when included simultaneously in a model predicting CT composition (Anderson, Williams, et al., 2015a, 2015b).

Finally, to determine the impact of sire Carcass Plus Index on carcass composition and carcass lean value, the Carcass Plus Index values were included in the base model along with their first order interactions with the fixed effects, and non-significant ($P > 0.05$) terms removed in a stepwise manner. The Carcass Plus Index combines the three breeding values (PWWT, PFAT and PEMD) into a single index value based on estimated economic weightings for each trait, and therefore was included in the models independently to the ASBVs of which it is comprised. Carcass Plus is designed to simplify the selection for improved HCWT and LMY% for producers of Terminal sired lambs in the Australian Sheep Industry, although the Index values are readily calculated for the Maternal and Merino sired lambs based on their values for weaning weight, PWWT, PFAT and PEMD. The Carcass Plus Index is currently based upon weightings for positive weaning weight breeding value (0.30), PWWT (0.35), and PEMD (0.30), and negative PFAT (0.05).

2.6 Estimating weights of lean tissue within sections

The models described above were used to estimate the lean weight for each carcass section. These were initially calculated at a constant carcass weight of 23kg, which was selected because this represents a relevant industry weight and lies well within the bounds of this dataset. The base model was used to estimate lean weight for the fore, saddle and hind section for the comparison between ewes versus wethers (within the progeny of Terminal sires), BLM dams versus Merino dams (within the progeny of Terminal sires), and Terminal versus Maternal or Merino sire types (within the wether progeny of Merino dams). The model with the 3 ASBVs was used to estimate $\log_e$ lean weights in each section for Maternal, Merino and Terminal sires at the extremes of their breeding value ranges for PFAT, PWWT, and PEMD (Table 2). In all cases, the lean weights estimated were back transformed to kilogram weight and the correction described by Sprugel (1983) applied to account for log-transformation error. The predicted weight of lean (kg) was subsequently used to determine the value of lean across the range of breeding values (see 2.7 calculating lean value). Similarly, the model containing the Carcass Plus index was used to estimate lean weights in each section for

Maternal, Merino and Terminal sires at the extremes of their Carcass Plus Index values (Table 2).

This procedure was then repeated to make these same comparisons at a constant slaughter age of 280 days. This age represents the raw mean age of lambs at the time of slaughter. In this instance, carcass weight was not held constant, but instead allowed to vary to reflect the true carcass weight for the comparisons being made. For example, the section lean weight of ewes was predicted at 23.5kg carcass weight, and wethers at 24.6kg carcass weight. The carcass weights used to predict lean weights for each sire type are summarised in Table 4 and were derived from the models described by Gardner et al. (2015). These weights were converted to $\log_e$ values prior to analysis.

2.7 Calculating lean value.

To determine carcass lean value the estimates of lean weight for each carcass section (kg), as described above, were multiplied by the average retail value of lean in each section and summed to arrive at a whole carcass lean value. The average retail values used were $17.33, $27.02 and $20.25 per kilogram for lean from the fore, saddle and hind sections. These values were determined using average retail prices of two major Australian lamb retailers (April 2015) for a set of commercial cuts (AUS-MEAT description codes (AUS-Meat Limited, 2015) in parenthesis) which included: 5 cuts from the fore section, eye of shoulder (5151), boneless shoulder (5047), fore-shank trim (5030), breast trim (5000), neck meat (5020), and fore-section lean trim (5290); 4 cuts from the saddle section, eye of shortloin (5150), tenderloin butt off (5082), eye of rack (5153), trimmed boneless flap (5173), and saddle section lean trim (5270); and 6 cuts from the hind section, topside (5073), round (5076), silverside (5071), rump (5130), butt tenderloin (5081), hind shank butt off (5031), and hind section lean trim (5270). Within each carcass section the average of these prices was calculated, after being weighted by the proportion that each cut represented of the total mass of lean for that section. The commercial cuts described above contain a small amount of subcutaneous and inter-muscular fat, however this would have little effect on the proportion that each cut represents of the total lean in each section, therefore having little impact on the overall estimate of lean value for that section.

3 Results

3.1 Impact of sex on carcass composition and lean value.

A comparison between sexes was only able to be made within the Terminal sired lambs. When compared at the same carcass weight, the carcass composition varied between sexes (P<0.01, Table 5), with wethers generally having more lean than ewes (Table 6). This was evident in the fore, saddle and hind sections where the wether progeny from BLM dams had 4.83%, 2.04% and 1.69% more lean than ewe lambs (Table 6). Likewise in lambs born to Merino dams, the wethers had 4.26%, 1.85% and 1.08% more lean than the ewe lambs in the fore, saddle and hind sections (Table 6). The decreased lean in the ewe lambs was largely offset by an increase in fat across all sections of the carcass (Table 6).

In a 23kg carcass, these compositional differences equated to an additional 0.38 kg and 0.31 kg of lean in wether lambs born to BLM and Merino dams, which was worth $7.55 and $6.27 per carcass more than ewe lambs (Table 7). The carcasses of wether lambs were also 1.07 kg heavier than ewe lambs at the same age (ie 280 days) (see Gardner et al. 2015). When this carcass weight difference was factored into the calculation the additional carcass lean was worth $19.22 and $16.81 for the wether lambs born to BLM and Merino dams (Table 7).

3.2 Impact of genetics on carcass composition and lean value in the carcass.

3.2.1 Sire type

Sire type comparisons were possible in wether lambs born to Merino dams. When compared at the same carcass weight, the amount of lean in each section varied between the Maternal, Merino and Terminal sired lambs (P<0.01, Table 5). For lean, 95% of the sire estimates lay between ±3.7%, ±5.4% and ±3.9% for the fore, saddle and hind sections respectively at any given carcass weight.

Compared to the Terminal sired lambs, the Maternal and Merino sired lambs had respectively 6.78% and 4.79% less lean in the saddle and 5.26% and 4.13% less lean in the hind section (Table 6). The Maternal sired lambs had the least fore section lean with 2.08% and 2.42% less lean than the Merino and Terminal sired lambs (Table 6) respectively.

When compared at the same carcass weight (23kg) these compositional differences equated to an additional 0.42kg and 0.62kg of lean in Terminal sired lambs compared to Merino and Maternal sired lambs, which was worth an extra $9.57 and $14.36 per carcass (Table 7).

Carcasses of Terminal sired lambs were 4.27kg and 1.48kg heavier than Merino and Maternal sired lambs at the same age (ie 280 days) (Gardner et al., 2015). When this carcass weight difference was factored into the calculation the additional carcass lean was worth $53.85 and $32.61 (Table 7).

3.2.2 Dam breed

A comparison of dam breeds was possible in the Terminal sired lambs. In the fore section, differences only existed within ewe lambs (*P*<0.01, Table 5), where the progeny of Merino dams had 1.46% more lean than those from BLM dams (Table 6). In the hind section, differences were evident within both sexes (*P*<0.01, Table 5), where lambs from Merino dams had 1.26% (wethers) and 1.90% (ewes) more lean than lambs from BLM dams (Table 6). In the ewe lambs the increased lean in Merino lambs was offset by reductions in fat within the fore, saddle and hind sections (3.1%, 4.28% and 2.41% respectively, Table 6) compared to lambs from BLM dams.

When compared at the same carcass weight (23kg), these compositional differences equated to an additional 0.17kg more lean in the progeny of Merino dams (average of wethers and females) compared to the progeny of BLM dams (Table 7). This resulted in Merino dams producing lambs with a predicted carcass lean value of $3.58 more, when compared to those born to BLM dams (Table 7). When compared at the same age, (280 days) the BLM dams produced lambs that on average had more lean (0.95kg, Table 7) and a carcass lean value that was $20.12 greater than the lambs from Merino dams.

3.2.3 Australian Sheep Breeding Values

3.2.3.1 Impact of sire PWWT on carcass composition and lean value

Sire PWWT had a significant effect on lean weight of the saddle section (*P*<0.01, Table 5). The magnitude of this effect varied between site-years, however on average saddle section lean weight increased at 0.28% per unit increase of PWWT ASBV (Table 6).

When lambs were compared at the same carcass weight (23kg), the lean value increase due to sire PWWT was similar for all three sire types (Table 8). However, due to their different breeding value ranges this meant that the impact of PWWT on lean value was greatest in Maternal sired lambs and worth an additional $5.59, compared to only $4.98 and $4.31 for the Terminal and Merino sired lambs (Table 8) across their respective ranges of sire PWWT.

Sire PWWT breeding value also had a marked effect on carcass weight which differed between sire types (Gardner et al., 2015). Thus when these differences between carcass weights (Table 4) were factored into the calculation at a constant age (280 days) the additional carcass lean was worth $3.95 per unit sire PWWT for the Merino sired lambs, compared to only $2.07, and $2.10 per unit sire PWWT for the Maternal, and Terminal sired lambs (Table 9). Across the range of sire PWWT breeding value for each sire type this equated to a total of $62.46, $38.39, and $28.20 for the Merino, Maternal, and Terminal sired lambs (Table 9).

3.2.3.2 Impact of sire PFAT on carcass composition and lean value

When compared at the same carcass weight, decreasing sire PFAT increased lean (P<0.01, Table 5) in all carcass sections. The greatest magnitude of effect was in the saddle region where at any given carcass weight a decrease in sire PFAT by one unit increased saddle lean by 2.74%, compared to increases of only 1.72% and 1.84% for lean in the fore and hind sections (Table 6). The increases in lean were accompanied by changes in the proportion of fat and bone in all carcass sections (P<0.05, Table 5) with the proportion of fat decreasing and bone increasing (Table 6). The impact of PFAT for all sections of the carcass was consistent across sites and years, although varied between kill groups (P<0.01, Table 5) (data not shown).

When compared at the same carcass weight (23kg), the increase in carcass lean value for each unit decrease in sire PFAT was similar for all three sire types (Table 6). Due to the different ranges of breeding values between sire types, this meant that the Terminal sired lambs had the greatest increase in carcass value ($30.05, Table 8), followed by the Maternal and Merino sired lambs ($28.36 and $22.70, Table 8).

Sire PFAT had a small impact on carcass weight that was consistent across sire types (Table 4)(Gardner et al., 2015). Therefore when lambs were compared at the same age, these increases in carcass weight resulted in a per unit value of lean of $8.42, $7.60 and $7.11 per unit decrease in PFAT for the Terminal, Maternal and Merino sire types (Table 9). Across the sire range of PFAT values for each sire type this equated to an increased lean value of $40.42, $35.71 and $27.03 for the Terminal, Maternal and Merino sired lambs (Table 9).

3.2.3.3 Impact of sire PEMD on carcass composition and lean value.

When compared at the same carcass weight, increasing sire PEMD increased lean in the saddle and hind sections (P<0.01, Table 5). In the saddle each unit increase in sire PEMD increased saddle lean by 1.99% (Table 6). In the hind section the effect varied between sire types. PEMD had minimal impact on the proportion of lean in the Merino sired lambs, however in the Terminal and Maternal sired lambs there was a 0.75 and 2.24% increase in hind section lean per unit of PEMD (Table 6). This increase in lean was largely off-set by carcass fat (P<0.01, Table 5) which when averaged across sire types was equivalent to a reduction in fat of 1.96%, 2.73% and 2.77% in the fore, saddle and hind sections per unit of increasing sire PEMD (Table 6).

When compared at the same carcass weight, Maternal sired lambs had the greatest increase in lean value per unit increase in PEMD ($4.30, Table 8), which was greater than both of the Terminal ($2.98) and Merino ($2.64) sired lambs (Table 8). Across their respective ranges of PEMD breeding values this equated to an increase in carcass lean value of $18.51, $23.22 and $13.70 for the Maternal, Terminal and Merino sired lambs (Table 8).

Sire PEMD had only a small impact on carcass weight which was consistent across sire types (Gardner et al., 2015). Thus when this was factored into the calculation and comparisons made at the same age, the Maternal sired lambs still had the greatest per unit increase in carcass lean value ($5.65, Table 9) compared to either the Terminal or Merino sired lambs. However, when calculated across the range of sire PEMD values within each sire type the Terminal sired lambs had the greatest increase in carcass lean value at $36.06 (Table 9), compared to $24.30 and $20.06 in the Maternal and Merino sired lambs.

3.2.3.4 Impact of sire Carcass Plus on carcass composition and lean value.

The sire Carcass Plus Index impacted on the saddle and hind section lean, with the impact on fore section dependent on sire type (P<0.01,Table 5). For every 10 units of increase in Carcass Plus there was an increase of 0.35% and 0.49% in fore section lean in the Maternal and Terminal sired lambs which amounted to a 4.2% and 3.7% increase in lean across their respective ranges of the Carcass Plus Index values (Table 6). The increase in lean for all sire types in the saddle and hind sections was 0.76 and 0.40% per 10 units of the Carcass Plus Index value (Table 6).

When lambs were compared at the same carcass weight (23kg), the Terminal and Maternal sired lambs had similar increase in lean value per unit of Carcass Plus ($0.15 and $0.13, Table 8), with a smaller impact on the lean value of Merino sired lambs ($0.09/ unit Carcass Plus). Across the range of Carcass Plus this equates to an increase of $11.27, $8.47 and $16.19 for the Terminal, Merino and Maternal sired lambs (Table 8).

Sire Carcass Plus Index also impacted on lamb carcass weight, although this varied across the three sire types (Table 4) with the Merino sired lambs having the greatest increase in HCWT per unit Carcass Plus (Table 4). When lambs were compared at the same age, the Merino sired lambs had the greatest increase in lean value of $0.54 per unit Carcass Plus (Table 9), compared to $0.48 and $0.37 for the Maternal and Terminal sired lambs (Table 9). When compared across their respective ranges of Carcass Plus this resulted in the greatest increase in lean value of $57.59 in the Maternal sired lambs (Table 9).

4 Discussion

4.1 The impact of genetics on the value of the lamb carcass.

4.1.1 The impact of sire type and dam breed on the value of the lamb carcass.

In support of our hypothesis, Terminal sired lambs had the greatest lean value when compared at the same carcass weight. This was a reflection of their greater lean weight across all three carcass sections compared to both Merino and Maternal sired lambs, consistent with their larger mature size and therefore reduced maturity when compared at the same weight (Huisman & Brown, 2008). On the basis of these differences the carcasses of Terminal sired lambs were worth $9.57 and $14.36 more than the Merino and Maternal sired lambs.

When compared at the same age, the difference between sire types was much greater due to their marked difference in carcass weights (Gardner et al., 2015). Thus the lean from the carcasses of Terminal sired lambs were worth $53.84 and $32.60 more than the Merino and Maternal sired lambs. These values also highlight the re-ranking of Merino and Maternal sired lambs, with Merino's more valuable when compared at the same carcass weight, but less valuable when carcass weight (and therefore growth rate) is factored in to the calculation. This partly contradicts the conclusions of Ponnampalam, Hopkins, Dunshea, et al. (2007) who stated that purebred Merino lambs will always be less productive in terms of carcass weight and muscle related productivity traits than Maternal sired lambs.

It should be noted that sire type comparisons are based on the mean of the sires in each sire type group. However within these groups considerable genetic variation exists between sires. This is well demonstrated by the breeding values described in Table 2, such that considerable overlap exists between the sires in each sire type group. Therefore while average differences exist between these groups, individual sires can still achieve the performance reported for other sire type groups.

Compared at the same carcass weight, Merino dams produced lambs that had more fore and hind lean compared to the BLM dams. This difference in lean weight was worth $3.58, and aligns well with the sire type effect discussed above where the lean from Merino lambs was worth $4.80 more than lambs from Maternal dams. Although not previously compared on a dollar basis, the mass differences align well with previous studies where, after correcting for carcass weight, lambs from BLM dams had less carcass lean (Anderson, Williams, et al., 2015a; Ponnampalam et al., 2008) and a higher proportion of fat (Anderson, Williams, et al., 2015b) than lambs from Merino dams.

The increased fatness of lambs from BLM genetics may be linked to their selection for improved reproduction capacity (Ferguson et al., 2010).

When compared at the same age, the opposite trend was evident, with lean value of the lambs from the BLM dams worth $20.12 more than that of the Merinos. Again, this aligns well with the sire type comparison between Merino and Maternal sires, reflecting the marked difference in carcass weights of lambs from these two dam breeds (Gardner et al., 2015)

4.1.2 The impact of Australian Sheep Breeding Values on carcass value

4.1.2.1 Post weaning C-site fat depth.

In support of our hypothesis, when comparing lambs at the same carcass weight, decreasing sire PFAT increased lean weight, corresponding with a substantial increase in the value of carcass lean. Furthermore, this increase in the value of lean across the range of PFAT ASBVs in the sired used, was substantially larger than the corresponding effects of PEMD or PWWT. This aligns well with previous work which showed that PFAT not only caused substantial increases in the mass of lean across the entire carcass, but also a favourable distribution of lean to the more highly valued saddle region (Anderson, Williams, et al., 2015a). This is in contrast to PEMD where only the weight/value of the saddle and hind sections were increased.

When lambs were compared at the same age, the difference in carcass lean value was still quite similar across the PFAT range. This reflects the relatively small effect of the PFAT breeding value on carcass weight, thus the main impact of PFAT on carcass value is via its effect on composition. The potential impact of PFAT on the retail lamb value through its impacts on eating quality (Pannier, Gardner, et al., 2014) and intramuscular fat (IMF) % (Pannier, Pethick, et al., 2014) in addition to the value of the lean meat are yet to be quantified.

4.1.2.2 Post weaning weight

The impact of PWWT on lean was predominantly focused on the saddle region, with no effects evident in the fore or hind sections, contrary to our initial hypothesis. Thus lean weight within the saddle increased across the PWWT range when compared at the same carcass weight, resulting in a small increase in carcass lean value. Previous analyses have demonstrated no overall increase in carcass lean weight due to the PWWT breeding value (Anderson, Williams, et al., 2015a), most likely because the small increases in saddle lean were masked by the lack of effect elsewhere.

In contrast to these small effects, when compared at the same age, sire PWWT had a marked impact on the lean value within the carcass, largely reflecting the substantial impact of this breeding value on carcass weight. Furthermore, lean value of the Merino sired lambs was almost twice the per unit increase evident within the Maternal and Terminal sired lambs. This is due to the greater impact of PWWT on carcass weight within the Merino sired lambs compared to the Terminal and Maternal sired lambs (Gardner et al., 2015).

4.1.2.3 Post weaning eye muscle depth

At any given carcass weight, increasing sire PEMD increased the weight of lean in the saddle and hind sections, with no significant increase in the fore section. These combined effects lead to a substantial increase in lean value, aligning well with our initial hypothesis. Earlier studies by Anderson, Williams et al. (2015a) showed that PEMD preferentially increased lean weight in the saddle at the expense of the fore section. Therefore it would be expected that the combined effects of the overall increase in lean weight and the lean redistribution away from the fore section would result in no net change to fore section lean weight. Likewise the overall increase in carcass lean weight, and the redistribution of lean to the saddle region would amplify the increase in lean weight in the more expensive saddle region cuts – as was evidenced in this study. The Maternal sired lambs had the greatest increase in carcass lean value per unit PEMD which was at least 1.5 times that of the Terminal and Merino sired lambs. The Merino sired lambs had only a small increase in hind section lean weight and therefore the smallest increase in lean value.

There was a significant increase in carcass weight caused by PEMD (Gardner et al., 2015), although this was a small in magnitude and consistent across all sire types, compared to the impact of sire PWWT. When lambs were compared at the same age the increase in lean value resulting from increasing sire PEMD for all sire types was greater than when lambs were compared at the same carcass weight.

4.1.2.4   Carcass plus

This breeding value index represents a way for lamb producers to select their Terminal sires on the basis of a weighted combination of PEMD, PWWT, and PFAT. This optimises the production of lambs that reach slaughter weights early, while maximising lean meat and maintaining a lean carcass. It is not used by Merino breeders as it does not incorporate selection for wool traits, with index selection in Maternal sires having more emphasis on traits such as number of lambs weaned and ewe resilience, including maintaining fat to optimise fertility. Despite these different selection pressures this analysis provides important information that quantify the effect of the Carcass Plus index on lean value in all sire types.

When lambs were compared at the same carcass weight, the Maternal and Terminal sired lambs had a similar increase in lean value per unit of Carcass Plus. The Merino sired lambs had less increase due to the negligible impact of Carcass Plus on the fore section of the carcass.

However, when lambs were compared at the same age, the Merino sired lambs had the greatest per unit increase in lean value compared to the other sire types. This is due to the heavy weighting of PWWT in the Index and the increased impact of PWWT on the carcass weight of the Merino sired lambs (Gardner et al., 2015).

This analysis provides important information regarding the impact of the Carcass Plus index on the value of lean in the carcass. In the future, similar analyses may provide some basis for restructuring the Carcass Plus Index to maximise lamb profitability. This was well demonstrated in one of our previous analyses (Anderson, Williams, Pannier, Pethick, & Gardner, 2013) which calculated the loss in retail carcass value when the emphasis on PFAT within the index was reduced from 30% to 5%, which was performed in order to maintain intramuscular fat at a level that did not negatively impact eating quality (Pannier, Gardner, et al., 2014; Pannier, Pethick, et al., 2014).

4.2 The impact of sex on the value of the lamb carcass

At the same carcass weight the wether lambs had more lean in all carcass sections resulting in greater carcass value equivalent to $6.46 within a 23kg carcass. The largest differences in lean weight were seen in the fore section, with the hind section showing the least differences in lean weight between the wethers and ewe lambs. However, given the high value of the saddle lean the difference within this tissue was amplified when expressed in dollar terms. The increase in lean in wethers when lambs are compared at the same weight (Anderson, Williams, et al., 2015a; Lee, Harris, Ferguson, & Jelbart, 1990; Ponnampalam et al., 2008) and age (Ponnampalam et al., 2008) has been reported previously, although not quantified holistically across carcass regions or expressed in dollar terms. These effects on composition are a reflection of the impact of sex on mature composition, with ewes being fatter than wethers (Anderson, Williams, et al., 2015b; Ponnampalam et al., 2008) and a reflection of mature size, with wethers being less mature and therefore leaner when compared at the same weight (Butterfield, 1988).

When comparisons were made at the same age, the mass difference between wethers and ewes was amplified, due to the more rapid growth rate and therefore heavier slaughter weights of wether lambs compared to ewes at the same age (Gardner et al., 2015). This leads to an even greater financial difference with lean value of wethers being $18.01 greater than ewes. This difference represents an important advantage for self-replacing ewe flocks where all wether lambs are slaughtered while the bulk of ewes are retained for breeding.

4.3 Comparison of effects

When compared at the same carcass weight, the biggest influence on carcass lean value was through the two breeding values, PFAT and PEMD. Reducing PFAT and increasing PEMD both increased carcass lean value, although the impact of both was greatest in Terminal sired lambs. This effect when assessed across the breeding value range was at least double the next largest factor – in this case the sire type difference between Terminal and Maternal sired lambs. It is possible that reducing sire PFAT and increasing PEMD has an even greater impact beyond its impact on lean weight and carcass weight due to the substantial decrease in carcass fat (Anderson, Williams, et al., 2015b; Gardner et al., 2010). These carcasses are less likely to attract penalties at processing plants for being over fat. The impact of gender was the next largest effect, with the difference between ewes and wethers only half the difference between Terminal and Maternal sired lambs. The PWWT breeding value had a relatively small effect, particularly when compared to the other two breeding values. The magnitude of effect of PWWT across the breeding value range was just over half the magnitude of the difference between genders. Lastly dam breed had a relatively small effect which was similar in magnitude to the impact of PWWT.

When lambs were compared at the same age this allowed for the differences in lamb size and therefore carcass weight at a given age to be included in the calculation of the weight and value of lean. There was marked re-ranking of magnitudes between the factors affecting value, predominantly driven by those which had the greatest impact on carcass weight. As such, the difference between Terminal and Merino sire types and the effect of the PWWT across its breeding value range, particularly within the Merino sires, had the largest impact on carcass lean value. The differences between genders and dam breeds also increased when differences in carcass weight at a given age were accounted for, yet these differences were still less than the effect of the PFAT and PEMD across their respective breeding value ranges.

4.4 Limitations and future work

This analysis enables the relative effects of gender and genetics on carcass lean to be evaluated without relying solely on a selected few cuts like the topside, and loin to indicate this value. However, allocating prices to this lean based on market prices as of April 2015 immediately exposes this analysis to currency issues due to price fluctuations. However, the ranking of prices for each cut within the lamb carcass has remained relatively constant over time (Pethick, Ball, Banks, & Hocquette, 2010), hence the results can still be interpreted with respect to the ranking of fore, saddle, and hind quarter lean within the carcass. Likewise, the effects identified in this paper are also likely to maintain their relative proportional differences.

Other limitations to this work are the additional factors that are impacted upon by the traits examined – particularly the carcass breeding values. For example the magnitude of the changes observed in bone and fat have not been incorporated into this financial evaluation which was instead restricted to the value of lean within the carcass. Indeed, this value differential could also be extended to include the costs of trimming of excessive fat from carcasses in the retail market. Likewise, this analysis does not capture the impact of genetic selection (carcass breeding values, dam breed, sire type) on the number of lambs weaned, feed efficiency, wool growth or ewe longevity. This more detailed economic analysis is beyond the immediate scope of this study, yet would certainly be of value to the industry when attempts are made to justify the introduction of new technologies to capture this value.

Lastly, the introduction of eating quality assessment through Meat Standards Australia (Meat Standards Australia, 2013), creates an opportunity for the associated effect on eating quality to be incorporated into the economic values. Work by Pannier, Gardner, et al. (2014) showed that selection for improved LMY% using increased sire PEMD and reduced sire PFAT had a negative impact on the eating quality of longissimus and semimembranosus samples, partially through their impact on intramuscular fat percentage. Therefore future multi-trait indexes are required that balance eating quality (reflected through intramuscular percentage) with the existing growth and carcass traits (Mortimer et al., 2014; Swan, Pleasants, & Pethick, 2015). More widespread introduction of technology that accurately assesses LMY%, IMF% and eating quality commercially and in breeding programs, alongside payment schemes that reward producers, would encourage the use of these multi index selection tools.

5 Conclusion

The results of this study enable the direct comparison of carcass lean value of different sire types, sexes and breeding values at the same carcass weight and at the same age. When compared at the same carcass weight sire PFAT had the greatest impact on carcass lean value, its magnitude of effect across the PFAT range being 1.5 times greater than the next most influential breeding value, PEMD. However when compared at the same age increasing sire PWWT had the greatest impact on carcass lean value, due to largely to its effect on carcass weight. Compared to lambs from other sire types, Terminal sired lambs had, on average, the greatest lean value irrespective of whether compared at the same weight or age, closely followed by Merinos when compared at the same weight, and Maternal sired lambs when compared at the same age.

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Table 1. Average age of lambs at slaughter and number of carcasses scanned using computed tomography in each lamb kill group at each site.

Site-Year	**Kill group**	**Average age (days)**	**Carcasses (n)**
Kirby 2007	1	235	72
	2	270	63
	3	352	96
Kirby 2008	1	269	97
	2	345	99
	3	408	99
	4	420	96
Rutherglen 2010	1	198	55
	2	254	59
Hamilton 2009	1	229	53
Struan 2010	1	260	67
	2	287	67
	3	322	27
Turretfield 2009	1	235	58
	2	262	63
	3	310	29
Katanning 2008	1	235	20
	2	242	29
	3	319	28
Katanning 2011	1	168	87
	2	238	96
	3	280	99
	4	355	95
Total	23	-	1554

Table 2. Number of sires and mean (min, max) for the Australian Sheep Breeding Values for post weaning weight (PWWT), post weaning c-site fat depth (PFAT) and post weaning eye muscle depth (PEMD) for each sire type of lamb carcasses undergoing computed tomography.

Sire type	No. of sires	PWWT (kg)	PFAT (mm)	PEMD (mm)	Carcass Plus
Maternal	67	4.7 (-6.1, 12.4)	-0.3 (-2.1, 2.6)	0.1 (-2.5, 1.8)	125 (63,184)
Merino	109	1.9 (-5.0, 10.8)	-0.2 (-1.9, 1.9)	0.0 (-2.6, 2.6)	112 (68,160)
Terminal	143	12.7 (5.3, 18.6)	-0.7 (-2.5, 2.3)	1.2 (-2.8, 5)	179 (133, 209)

Table 3. Number of lamb carcasses analysed in the base model according to sex, sire type, birthing and rearing type and dam breed.

	Sex		**Birth type-rearing type**						**Dam breed**	
	Female	**Wether**	**Single born and raised**	**Born as twin-raised as single**	**Born as twin-raised as twin**	**Born as triplet-raised as single**	**Born as triplet-raised as twin**	**Born and raised as triplet**	**Merino**	**BLM[1]**
Maternal	0	332	152	25	141	2	8	4	332	0
Merino	0	251	129	38	79	1	0	4	251	0
Terminal	475	496	379	91	447	8	24	22	457	514
Total	475	1079	660	154	667	11	32	30	1040	514

[1] BLM: Border Leicester-Merino

Table 4. Predicted carcass weights (kg) ± SE of the Maternal, Merino and Terminal sired wether lambs born to Merino dams at an average age of 280 days.

Sire type	Base model (no breeding values)	PWWT (kg)			PEMD (mm)			PFAT (mm)			Carcass Plus		
		Range (low, high)	PWWT low	PWWT high	Range (low, high)	PEMD low	PEMD high	Range (low, high)	PFAT low	PFAT high	Range (low, high)	Carcass plus low	Carcass plus high
	Carcass weight (kg)		Carcass weight (kg) [1]			Carcass weight (kg) [1]			Carcass weight (kg) [1]			Carcass weight (kg) [1]	
Maternal	21.9 ± 0.18	(-6.1, 12.4)	20.0 ± 0.53	23.3 ± 0.36	(-2.5, 1.8)	21.5 ± 0.23	22.1 ± 0.21	(-2.1, 2.6)	22.2 ± 0.24	21.3 ± 0.26	(64,184)	19.0 ± 0.60	24.6 ± 0.52
Merino	19.1 ± 0.22	(-5.0, 10.8)	16.3 ± 0.32	21.9 ± 0.33	(-2.6, 2.6)	18.3 ± 0.25	19.1 ± 0.25	(-1.9, 1.9)	19.1 ± 0.25	18.3 ± 0.26	(69,160)	17.2 ± 0.42	21.2 ± 0.32
Terminal	23.4 ±0.19	(5.3, 18.6)	22.2 ± 0.29	24.6 ± 0.28	(-2.8, 5)	22.9 ± 0.26	24.1 ± 0.26	(-2.5, 2.3)	23.9 ± 0.21	22.9 ± 0.27	(134, 209)	22.4 ± 0.31	24.5 ± 0.30

PWWT: post weaning weight; PFAT: post weaning c-site fat depth; PEMD: post weaning eye muscle depth

[1] The carcass weight for each sire type has been predicted at the maximum and minimum Australian Sheep Breeding Value range for that particular sire type as described in Table 2 using models and data from Gardner et al. (2015).

Table 5. F-values and degrees of freedom for the numerator(NDF) and denominator (DDF) for factors affecting the weight of fat, lean and bone in the fore, saddle and hind sections of the lamb carcass.

		Fore-section			Saddle section			Hind section		
Effect	**NDF,DDF**	**Fat**	**Lean**	**Bone**	**Fat**	**Lean**	**Bone**	**Fat**	**Lean**	**Bone**
Core model										
Site-year	7,171	13.24**	82.05**	43.13**	49.31**	38.24**	29.33**	54.11**	35.82**	85.21**
Sex(sire type)	1,171	35.86**	156.21**	43.30**	151.57**	19.84**	3.37	41.65**	21.52**	31.89**
Sire type	2,171	21.31**	5.13**	17.46**	8.56**	26.13**	1.31	13.67**	30.86**	14.8**
Kill group(site-year)	15,171	3.21**	9.15**	11.86**	9.88**	11.12**	6.95**	9.53**	4.89**	11.46**
Dam breed(sire type)	1,171	5.83*	8.33**	2.24	11.07**	1.78	0.19	2.76	9.04**	0.09
Site-year x sire type	12,171	2.82**	1.24	0.76	2.57**	3.11**	1.16	4.01**	3.00**	1.90*
Site-year x dam breed (sire type)	5,171	2.08	5.88**	2.29*	4.42**	1.89	0.32	3.32**	2.50*	1.96
$\log_e$ (CT whole carcass wt (kg))	1,171	2308.07**	3729.09**	1109.13**	2446.08**	2383.67**	615.23**	2332.49**	4582.8**	1525.07**
Australian Sheep Breeding Values										
PWWT	1,153	3.41	0.01	0.09	0.35	8.67**	0.48	3.69	0.6	0.06
PWWT x site-year	7,153	2.84**	1.67	1.27	3.88**	3.43**	1.14	3.84**	4**	3.48**
PFAT	1,153	44.4**	29.17**	9.2**	70.12**	49.65**	6.06*	58.53**	48.56**	8.77**
PFAT x Kill group(site-year)	22,153	1.34	1.28	1.33	1.33	1.75*	1.78*	1.93*	1.75*	1.79*
PEMD	1,153	14.75**	3.24	1.96	24.33**	53.23**	0.12	42.16**	31.64**	0.09
PEMD x sire type	2,153	2.07	1.47	0.46	8.13**	2.84	1.12	4.48*	6.14**	1.60
Carcass plus										
Carcass plus	1,167	12.14**	1.31	0.17	5.05*	22.53**	0.16	14.2**	12.64**	0.01
Carcass Plus x sire type	2,167	1.65	3.61*	1.03	2.72	2.24	0.44	1.15	1.60	1.48

NDF, DDF: numerator and denominator degrees of freedom.
* $P<0.05$, **$P<0.01$

Table 6. The relative change (% change in weight) for fat, lean and bone in the fore, saddle and hind sections of the carcass due to sex, sire type, dam breed and Australian Sheep Breeding Value effects for lambs slaughtered at 23kg.

		Fore section (% change in weight)			**Saddle section (% change in weight)**			**Hind section (% change in weight)**		
Effect	**Level**	**Fat**	**Lean**	**Bone**	**Fat**	**Lean**	**Bone**	**Fat**	**Lean**	**Bone**
Sex dambreed (sire type)[1]	Maternal x Merino M	**10.92^{d}**	**-2.42^{c}**	**1.36^{c}**	**10.05^{b}**	**-6.78^{a}**	**-0.58^{ab}**	**8.17^{d}**	**-5.26^{a}**	**0.23^{c}**
	Merino x Merino M	**6.31^{c}**	**-0.35^{d}**	**5.63^{d}**	**1.08^{a}**	**-4.79^{b}**	**1.80^{b}**	**4.00^{bc}**	**-4.13^{ab}**	**4.37^{d}**
	Terminal x BLM F	**6.61^{c}**	**-5.64^{a}**	**-4.32^{a}**	**14.38^{c}**	**-3.01^{bc}**	**-1.9^{a}**	**6.19^{cd}**	**-2.93^{b}**	**-2.76^{a}**
	Terminal x Merino F	**3.30^{b}**	**-4.26^{b}**	**-2.90^{ab}**	**9.48^{b}**	**-1.85^{cd}**	**-0.10^{ab}**	**3.63^{b}**	**-1.08^{c}**	**-1.89^{ab}**
	Terminal x BLM M	**1.74^{ab}**	**-0.81^{d}**	**0.25^{c}**	**2.92^{a}**	**-0.97^{de}**	**0.96^{ab}**	**0.19^{a}**	**-1.24^{c}**	**0.32^{c}**
	Terminal x Merino M	**0.00^{a}**	**0.00^{d}**	**0.00^{bc}**	**0.00^{a}**	**0.00^{e}**	**0.00^{ab}**	**0.00^{a}**	**0.00^{d}**	**0.00^{bc}**
Australian Sheep Breeding Values[2]										
PWWT		-0.28	-0.01	-0.04	-0.10	**0.28**	0.13	-0.32	0.05	0.02
PWWT x site-year	Kirby 2007	**-0.97**	0.13	0.28	**-0.89**	**0.37**	0.03	**-0.39**	**0.31**	**0.47**
	Kirby 2008	**-0.11**	0.06	0.05	**-0.45**	-0.05	0.15	**0.18**	0.07	-0.01
	Rutherglen 2010	**-0.47**	0.12	-0.12	**-0.33**	**0.41**	-0.19	**-1.42**	**0.38**	**0.16**
	Hamilton 2009	**0.28**	-0.09	0.09	**0.42**	**-0.14**	0.28	**0.14**	**-0.18**	**-0.17**
	Struan 2010	**-0.40**	-0.22	-0.31	**0.22**	**0.25**	-0.38	0.02	-0.06	-0.06
	Turretfield 2009	**0.23**	-0.21	-0.22	**0.83**	**0.21**	0.05	**0.34**	-0.29	**-0.50**
	Katanning 2008	**-0.49**	0.02	-0.28	**-0.65**	**1.06**	0.79	**-1.31**	0.15	**0.22**
	Katanning 2011	**-0.31**	0.13	0.15	0.00	0.11	0.32	**-0.14**	0.01	0.08
PFAT		**3.87**	**-1.72**	**-1.56**	**6.25**	**-2.74**	**-1.75**	**5.15**	**-1.84**	**-1.07**
PEMD		**-1.96**	0.62	-0.40	**-2.73**	**1.88**	-0.19	**-2.77**	**1.16**	-0.19
PEMD x sex dambreed	Maternal x Merino M	**-3.17**	0.61	-0.63	-6.27	2.89	1.16	-5.30	**2.24**	0.74
(sire type)	Merino x Merino M	**-0.69**	-0.07	-0.98	-0.39	2.39	0.01	-3.25	**0.40**	0.10
	Terminal x BLM F	**-2.29**	1.00	0.24	-2.71	1.35	-1.61	-1.46	**1.28**	-0.49
	Terminal x Merino F	**-1.77**	0.40	-0.29	-2.37	1.46	-0.10	-1.83	**1.07**	-0.31
	Terminal x BLM M	**-2.31**	0.87	-0.32	-2.88	1.51	0.09	-2.64	**1.23**	-0.28
	Terminal x Merino M	**-1.51**	0.91	-0.42	-1.75	1.71	-0.71	-2.12	**0.75**	-0.93
Carcass Plus[3]										

Carcass Plus		**-0.96**	**0.25**	-0.09	**-0.80**	**0.76**	-0.03	**-0.88**	**0.40**	-0.15
Carcass Plus x sex dambreed (sire type)	Maternal x Merino M	-0.90	**0.35**	-0.43	-1.39	0.88	0.03	-1.43	0.56	-0.10
	Merino x Merino M	-0.23	**-0.22**	0.21	0.08	0.14	0.28	-0.34	0.12	0.30
	Terminal x BLM F	-1.54	**0.47**	0.13	-0.67	0.93	-0.81	-0.58	0.63	-0.42
	Terminal x Merino F	-1.00	**-0.04**	0.17	-0.80	0.85	0.59	-0.71	0.36	-0.18
	Terminal x BLM M	-1.31	**0.43**	-0.54	-1.12	1.07	0.07	-1.43	0.53	-0.32
	Terminal x Merino M	-0.79	**0.49**	-0.05	-0.93	0.71	-0.35	-0.80	0.20	-0.20

M = wether; F = ewe; BLM: Border Leicester- Merino

PWWT: post weaning weight; PEMD: post weaning eye muscle depth; PFAT: post weaning c-site fat depth

[1] [a–e] Within columns for sexdambreed(sire type), % change values without a common superscript differ significantly at $P < 0.05$ and represents the difference in $\log_e y$ values for each fixed effect compared to the fixed effect with coefficient 0.00 expressed as a percentage.

[2] % change in weight: the % increase or decrease in each tissue type per unit of Australian Sheep Breeding Value (PWWT, PFAT, PEMD)

[3] % change in weight: the % increase or decrease in each tissue type per 10 units of the Carcass Plus breeding value

Effects in bold are significant P<0.05

Table 7. Weight (kg) and value ($) of lean in the fore, saddle and hind sections of the lamb carcass at the same weight (23 kg) and the same age (280 days).

		Fore-section		Saddle-section		Hind-section		Whole carcass	
Effect	**Level**	**Lean weight (kg)**	**Lean value ($)**	**Lean weight (kg)**	**Lean value ($)**	**Lean weight (kg)**	**Lean value ($)**	**Lean weight (kg)**	**Lean value ($)**
				Lambs compared at the same carcass weight (23kg)					
Sexdambreed	Maternal x Merino M	4.28	74.13	3.45	93.29	5.10	103.36	12.83	270.79
(sire type)	Merino x Merino M	4.37	75.71	3.53	95.28	5.16	104.59	13.06	275.58
	Terminal x BLM F	4.14	71.69	3.59	97.07	5.23	105.90	12.96	274.66
	Terminal x Merino F	4.20	72.73	3.64	98.23	5.33	107.92	13.17	278.88
	Terminal x BLM M	4.35	75.36	3.67	99.11	5.32	107.75	13.34	282.21
	Terminal x Merino M	4.38	75.97	3.70	100.08	5.39	109.10	13.47	285.15
				Lambs compared at the same age (280 days)					
Sexdambreed	Maternal x Merino M	4.10	71.04	3.19	86.19	4.91	99.45	12.20	256.68
(sire type)	Merino x Merino M	3.72	64.46	3.00	81.06	4.44	89.93	11.16	235.44
	Terminal x BLM F	4.40	76.24	3.81	102.94	5.54	112.21	13.75	291.39
	Terminal x Merino F	4.10	71.04	3.55	95.92	5.21	105.53	12.86	272.48
	Terminal x BLM M	4.80	83.17	4.04	109.16	5.84	118.29	14.68	310.61
	Terminal x Merino M	4.45	77.10	3.76	101.59	5.46	110.59	13.67	289.29

M = wether; F = ewe; BLM: Border Leicester-Merino

Table 8. Predicted carcass value for the fore, saddle and hind sections of carcass for the Maternal, Merino and Terminal sired lambs for the range of post weaning weight (PWWT), c-site fat depth (PFAT), c-site eye muscle depth (PEMD) and Carcass Plus Index values – wether progeny of Merino dams at 23kg carcass weight.

Sire type	**Breeding value**	**Fore section lean value ($)**	**Saddle section lean value ($)**	**Hind section lean value ($)**	**Carcass value ($)**	**$ difference (high-low)**	**$ per unit breeding value**
	PWWT						
Maternal	Low (-6.1)	74.65	92.11	103.52	270.28		
Maternal	High (12.4)	74.52	96.88	104.48	275.87	5.59	0.30
Merino	Low (-5)	76.70	96.31	106.53	279.54		
Merino	High (10.8)	76.58	100.57	107.38	284.52	4.98	0.32
Terminal	Low (5.3)	75.46	98.52	106.30	280.28		
Terminal	High (18.6)	75.36	102.22	107.01	284.58	4.31	0.32
	PFAT						
Maternal	PFAT low (-2.1)	76.93	99.67	107.55	284.15		
Maternal	PFAT high (2.6)	70.71	86.83	98.25	255.79	-28.36	-6.03
Merino	PFAT low (-1.9)	76.64	98.17	106.89	281.69		
Merino	PFAT high (1.9)	71.63	87.94	99.41	258.99	-22.70	-5.97
Terminal	PFAT low (-2.5)	77.78	105.64	110.26	293.68		
Terminal	PFAT high (2.3)	71.36	91.75	100.52	263.63	-30.05	-6.26
	PEMD						
Maternal	PEMD low (-2.5)	73.72	89.45	96.69	259.85		
Maternal	PEMD high (1.8)	75.68	96.68	106.00	278.36	18.51	4.30
Merino	PEMD low (-2.6)	75.76	92.56	106.40	274.71		
Merino	PEMD high (2.6)	78.20	101.61	108.61	288.42	13.70	2.64
Terminal	PEMD low (-2.8)	74.07	91.86	105.40	271.33		
Terminal	PEMD high (5.0)	77.65	105.33	111.57	294.54	23.22	2.98
	Carcass Plus						
Maternal	Carcass Plus low (64)	72.29	90.51	102.04	264.84		
Maternal	Carcass Plus high (184)	75.32	98.76	106.94	281.03	16.19	0.13

Merino	Carcass Plus low (69)	76.30	90.79	102.23	269.32		
Merino	Carcass Plus high (160)	74.77	97.07	105.96	277.80	8.47	0.09
Terminal	Carcass Plus low (134)	74.36	94.64	104.70	273.69		
Terminal	Carcass Plus high (209)	77.09	100.03	107.84	284.96	11.27	0.15

PWWT: post weaning weight; PEMD: post weaning eye muscle depth; PFAT: post weaning c-site fat depth

Table 9. Predicted carcass value for the fore, saddle and hind sections of carcass for the Maternal, Merino and Terminal sired lambs for the range of post weaning weight (PWWT), c-site fat depth (PFAT), c-site eye muscle depth (PEMD) and Carcass Plus Index values – wether progeny of Merino dams at 280 days of age.

Sire type	**Breeding value**	**Fore section lean value ($)**	**Saddle section lean value ($)**	**Hind section lean value ($)**	**Carcass value ($)**	**$ difference (high-low)**	**$ per unit breeding value**
	PWWT						
Maternal	Low (-6.1)	66.10	81.70	92.26	240.06		
Maternal	High (12.4)	75.23	97.79	105.42	278.44	38.39	2.07
Merino	Low (-5)	57.33	72.30	80.87	210.50		
Merino	High (10.8)	73.38	96.44	103.13	272.96	62.46	3.95
Terminal	Low (5.3)	73.30	95.75	103.42	272.47		
Terminal	High (18.6)	79.73	108.06	112.88	300.67	28.20	2.10
	PFAT						
Maternal	PFAT low (-2.1)	74.74	96.88	104.65	276.28		
Maternal	PFAT high (2.6)	66.15	81.32	93.09	240.57	-35.71	-7.60
Merino	PFAT low (-1.9)	65.27	83.79	91.81	240.87		
Merino	PFAT high (1.9)	58.85	72.46	82.52	213.84	-27.03	-7.11
Terminal	PFAT low (-2.5)	80.39	109.13	113.76	303.28		
Terminal	PFAT high (2.3)	71.14	91.48	100.23	262.86	-40.42	-8.42
	PEMD						
Maternal	PEMD low (-2.5)	69.47	84.38	91.41	245.27		
Maternal	PEMD high (1.8)	73.23	93.60	102.74	269.57	24.30	5.65
Merino	PEMD low (-2.6)	62.32	76.37	88.44	227.14		
Merino	PEMD high (2.6)	66.76	86.94	93.50	247.20	20.06	3.86
Terminal	PEMD low (-2.8)	73.82	91.56	105.07	270.45		
Terminal	PEMD high (5.0)	80.89	109.65	115.97	306.51	36.06	4.62
	Carcass Plus						
Maternal	Carcass Plus low (64)	66.10	81.70	92.26	240.06		
Maternal	Carcass Plus high (184)	79.89	104.67	113.08	297.64	57.59	0.48
Merino	Carcass Plus low (69)	57.33	72.30	80.87	210.50		
Merino	Carcass Plus high (160)	69.69	90.55	99.12	259.36	48.86	0.54
Terminal	Carcass Plus low (134)	73.30	95.75	103.42	272.47		
Terminal	Carcass Plus high (209)	81.33	105.48	113.45	300.26	27.79	0.37

PWWT: post weaning weight; PEMD: post weaning eye muscle depth; PFAT: post weaning c-site fat depth

Highlights

- Selection for increased lean meat yield using Australian Sheep Breeding Values increases carcass value.
- At equal carcass weight, reduced sire breeding values for c-site fat depth increases carcass lean value the most.
- At equal age, increased sire growth breeding values increases carcass lean value the most.
- Terminal sired lambs have higher carcass lean value than Maternal and Merino sired lambs.